NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

TECHNICAL NOTE

No. 1250

EFFECT OF BLADE STALLING ON THE EFFICIENCY OF A

HELICOPTER ROTOR AS MEASURED IN FLIGHT

By F. B. Gustafson and Alfred Gessow

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE NO. 1250

EFFECT OF BLADE STALLING ON THE EFFICIENCY OF A

HELICOPTER ROTOR AS MEASURED IN FLIGHT

By F. B. Gustafson and Alfred Gessow

SUMMARY

Performance data on a helicopter rotor were obtained in flight
over a range of combinations of thrust coefficient and tip-speed
ratios which included combinations intended to result in blade
stalling. The data thus obtained were analyzed by plotting the ratio
of measured values of rotor profile drag–lift ratio to theoretical
values against the calculated angles of attack at the tip of the
retreating blade. The theory used for calculating the drag–lift
ratios intentionally omits any allowance for stalling. This ratio
is close to unity until a tip angle of attack of about 12° is reached;
then it rises abruptly and reaches a value of about 2 at 16°. Whereas
the pilot was able to handle the helicopter until the blade–section
stall angle in the region of the tip was exceeded by about 4°, the
performance losses began about as tip stalling set in.

The study further indicated that the calculated angle of attack
of the retreating tip should be a useful parameter in connection with
both theoretical and experimental studies of helicopter performance,
inasmuch as it is shown to define adequately the conditions at which
stalling losses set in for a range of combinations of thrust coeffi-
cient and tip–speed ratio.

INTRODUCTION

A question concerning rotor–blade stalling, which has appeared
to warrant further experimental study, is the effect on power required.
It is of interest to know whether stalling materially reduces rotor
efficiency before the operating limitation due to vibration and loss
of control (see reference 1) is reached as calculations made by the
weighting–curve method of reference 2 indicated. Data substantiating
this prediction have been obtained by the Langley Flight Research
Division and are presented herein.

APPARATUS AND METHODS

The measurements were made on the Sikorsky HNS-1 (Army YR-4B) helicopter, shown in figure 1 and described in reference 3, equipped with a plywood-covered set of main-rotor blades which incorporated −8° of linear twist (tip pitch lower than root pitch). These blades have a relatively low solidity (0.042). The airfoil section used is a reflexed NACA 23015 profile which differed materially from the true section as regards leading-edge shape and maximum thickness, although all flats and depressions were faired out with filler. These deviations from the true contour probably appreciably reduced the stalling angle for this airfoil section. Wind-tunnel data on sample airfoil sections representing the actual contour are not available but are not essential for the purpose of the present paper. A complete listing of the quantities measured and a description of the method of reduction of data are given in reference 3. A detailed description of the rotor blades is given in reference 4.

TEST CONDITIONS

Data were obtained for thrust coefficients C_T ranging from 0.0040 to 0.0060 and tip-speed ratios μ ranging from 0.11 to 0.24. The combinations of thrust coefficient and tip-speed ratio were initially chosen to produce calculated tip angles of attack of the retreating blade $\alpha_{(1.0)(270°)}$ of 16° or less, and the pilot's comments concerning these various combinations showed that this limitation could not be exceeded without excessive vibration and control difficulties.

ANALYSIS OF DATA

In order to separate the effects of stalling from the effects of thrust coefficient and tip-speed ratio anticipated without stalling, the data have been analyzed by plotting the ratio of measured values of drag-lift ratios $(D/L)_{O_m}$ to theoretical values $(D/L)_{O_t}$ against calculated tip angle. (See fig. 2.) The theory used for calculating the drag-lift ratios intentionally omits any allowance for stalling. These values were obtained from unpublished theory paralleling that given in reference 5 but worked out for the appropriate blade twist.

RESULTS AND DISCUSSION

Figure 2 indicates that the ratio of experimental values of profile drag-lift ratios to theoretical values is close to unity for calculated tip angles of attack below about 12°. As higher tip angles are reached the scatter increases and the ratio rises; a value of about 2 is indicated for a tip angle of 16°. Limited camera observations of tuft action which paralleled those in reference 1 were made in order to establish the correlation between this rise and the occurrence of blade stalling. These observations were sufficient to indicate that stalling begins on the outer (and most important) part of the blade at a calculated tip angle of about 12° and that this part of the blade is stalled for about one-quarter of each revolution at a tip angle of 16°.

The data of figure 2 show no apparent difference in correlation for the various thrust coefficients; thus, the tip angle for which stalling losses begin appears to be a unique value, unaffected (within the limits of the experimental accuracy) by the particular combination of thrust coefficient and tip-speed ratio which produces it. Also, the scatter of the ratios before the tip angle for stalling is reached is generally quite low inasmuch as the deviation from the mean for most of these points represents only about 1 or 2 percent of the total rotor-shaft power, which is the minimum experimental error anticipated. Other methods of plotting which were tried, such as measured profile drag-lift ratio against tip-speed ratio for arbitrary groups of thrust coefficients, showed relatively large apparent scatter, most of which is actually due to stalling. It is concluded that the method used in figure 2, and most particularly the use of the calculated tip angle, should be valuable in analyzing experimental data whenever stalling losses are anticipated.

Figure 3 shows how the theoretical variation of rotor drag-lift ratio with tip angle of attack for a tip-speed ratio μ of 0.25 would be modified by an allowance for stalling losses based on figure 2. The choice of $\mu = 0.25$ is pertinent because it represents the maximum value reached in these tests and because theory shows it to be nearly optimum as regards profile drag-lift ratio. The charts of reference 5 and the corresponding unpublished charts for -8° twist indicate that the slope of the curve of figure 3 with stalling losses omitted (solid line) may be considered typical for the tip-speed ratios and power loadings reached with current helicopters. The losses due to stalling are then seen to outweigh greatly the gains otherwise anticipated from use of higher blade-section tip angles of attack.

It is significant that, whereas the pilot was able to handle the helicopter until the stall angle in the region of the tip was exceeded by approximately 4°, the performance losses began about as tip stalling set in. Further, since the optimum profile drag-lift ratio is shown to occur approximately as stalling sets in (fig. 3), the lines of constant tip angle of attack, which were originally put on the theoretical drag-lift ratio charts of reference 5 as limiting the application of the theory, are seen to be applicable as lines of optimum performance as well.

CONCLUSIONS

For the helicopter rotor tested and for the range of combinations of thrust coefficient and tip-speed ratio covered, the analysis indicated the following conclusions:

1. Whereas the pilot was able to handle the helicopter until the blade-section stall angle in the region of the tip of the retreating blade was exceeded by about 4°, the performance losses due to stalling began about as tip stalling set in. The profile-drag losses approximately doubled by the time the limitation resulting from excessive vibration and control difficulties was reached.

2. Calculation of conditions corresponding to a fixed value of the angle of attack of the retreating blade tip is a useful approach in determining the conditions for optimum performance as well as in limiting the applicability of theoretical treatments lacking specific allowance for stalling losses.

3. A plot of the ratio of experimental values of profile drag-lift ratios to theoretical values against the calculated angle of attack of the tip of the retreating blade is an effective means of analyzing experimental measurements of rotor performance when stalling losses are anticipated.

Langley Memorial Aeronautical Laboratory
      National Advisory Committee for Aeronautics
            Langley Field, Va., February 13, 1947

REFERENCES

1. Gustafson, F. B., and Myers, G. C., Jr.: Stalling of Helicopter
   Blades. NACA TN No. 1083, 1946.

2. Gustafson, F. B.: Effect on Helicopter Performance of Modifications
   in Profile-Drag Characteristics of Rotor-Blade Airfoil Sections.
   NACA ACR No. L4H05, 1944.

3. Gustafson, F. B.: Flight Tests of the Sikorsky HNS-1 (Army YR-4B)
   Helicopter. I - Experimental Data on Level-Flight Performance
   with Original Rotor Blades. NACA MR No. L5C10, 1945.

4. Gustafson, F. B., and Gessow, Alfred: Flight Tests of the Sikorsky
   HNS-1 (Army YR-4B) Helicopter. II - Hovering and Vertical-
   Flight Performance with the Original and an Alternate Set of
   Main-Rotor Blades, Including a Comparison with Hovering
   Performance Theory. NACA MR No. L5D09a, 1945.

5. Bailey, F. J., Jr., and Gustafson, F. B.: Charts for Estimation
   of the Characteristics of a Helicopter Rotor in Forward Flight.
   I - Profile Drag-Lift Ratio for Untwisted Rectangular Blades.
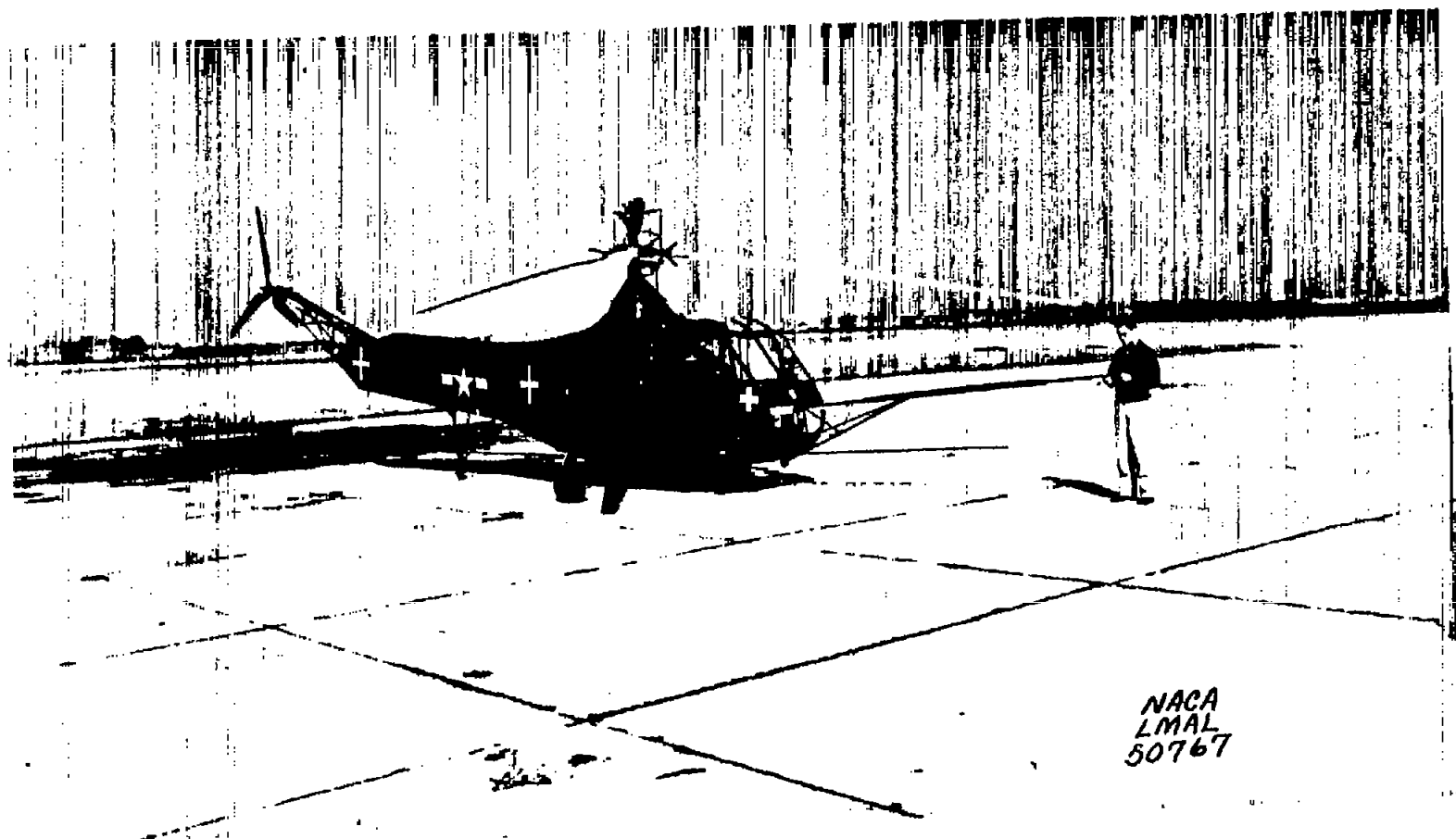   NACA ACR No. L4H07, 1944.

Figure 1.- Helicopter equipped with a twisted, plywood-covered set of
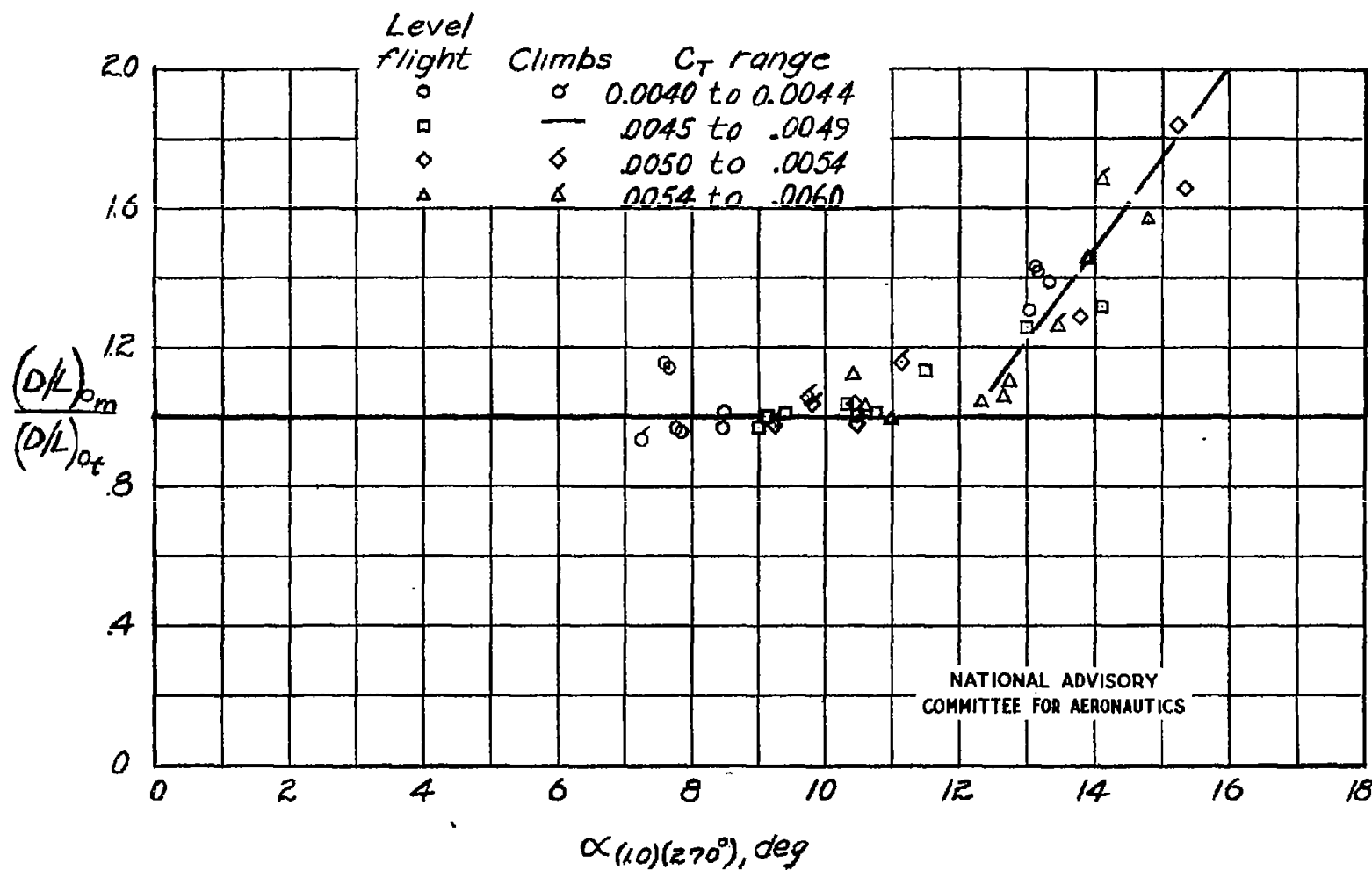main-rotor blades.

Fig. 1

Figure 2.- Variation of the ratio of measured values of rotor-profile drag-lift ratio to theoretical values $\dfrac{(D/L)_{o_m}}{(D/L)_{o_t}}$ with the calculated angle of attack of the retreating blade tip $\alpha_{(1.0)(270°)}$.
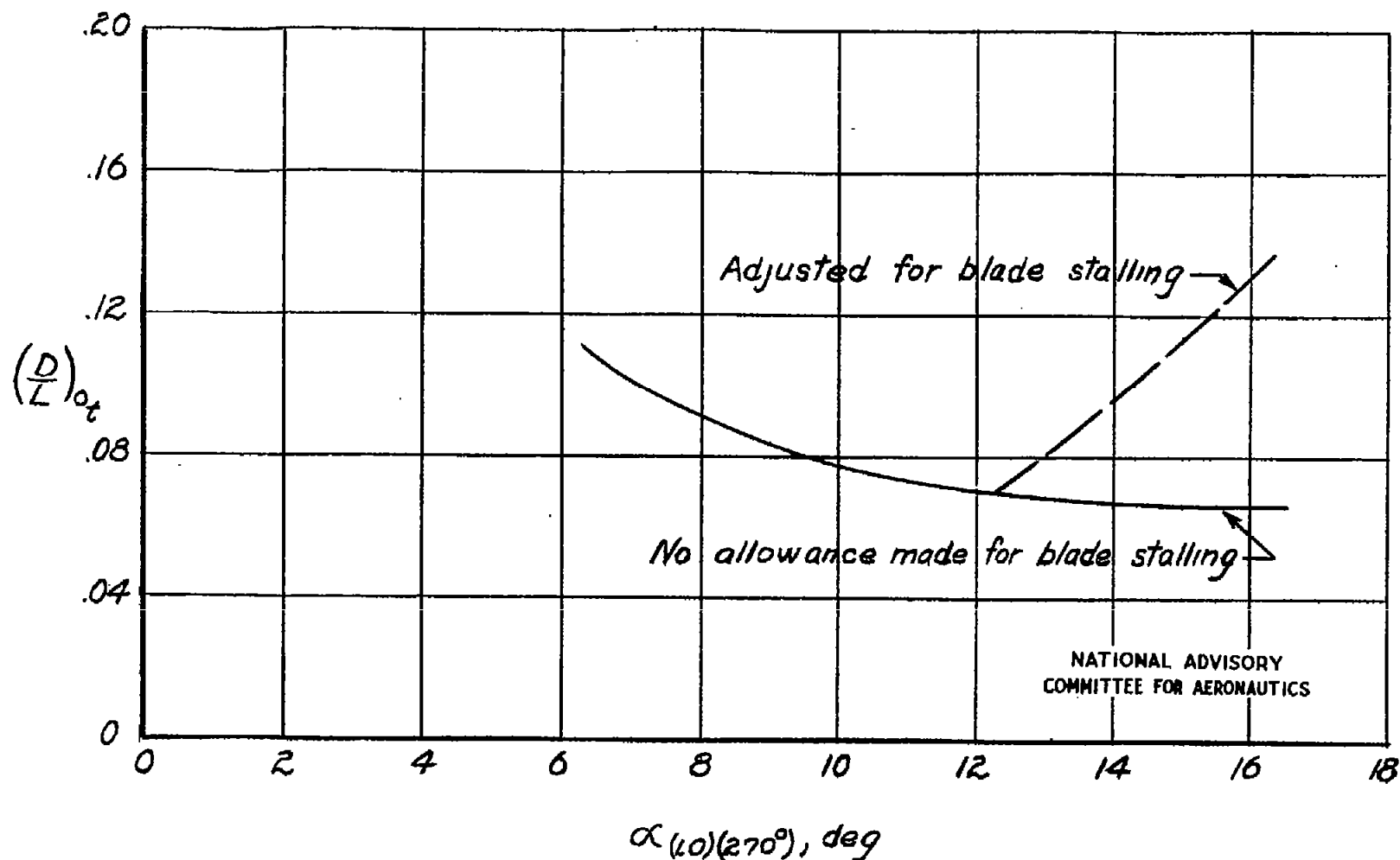
Fig. 2

Fig. 3

Figure 3.- Variation of the theoretical rotor profile drag-lift ratio $(D/L)_{o_t}$ with the calculated angle of attack of the retreating blade tip $\alpha_{(1.0)(270^0)}$. Tip-speed ratio $\mu = 0.25$.